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ScienceDirect

Energy Procedia 1 (2009) 4039–4046

Energy Procedia

www.elsevier.com/locate/procedia

GHGT-9

Technology Comparison of CO_2 Capture for a Gas-to-Liquids Plant

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Abstract

The accelerating pace of climate change regulatory action has rendered it necessary to understand the potential impact of carbon constraints on unconventional hydrocarbon resources such as gas-to-liquids (GTL). A systematic evaluation approach was applied to a GTL plant:

1. Estimate carbon dioxide (CO_2) emissions from a GTL plant.
2. Determine the cost of CO_2 capture with retrofit, conventional facilities.
3. Determine the CO_2 capture cost for alternate technology, oxy-firing plant heaters.
4. Determine the cost of CO_2 capture integrated into the original design.

Results from stages one through three are included. The capital and operating costs of the capture technologies are compared.

Gas-to-Liquids (GTL); Carbon Dioxide Capture; post-combustion capture; oxy-firing; unconventional resources

1. Introduction

As regulatory action around climate change continues to increase, the energy industry will need to consider the impact of CO_2 emission mitigation on existing operations and the development of new resources. As unconventional resources grow in importance in the overall energy equation, the industry is studying the potential impact of carbon constraints on projects such as heavy and extra-heavy oil upgrading, coal to liquids (CTL), biomass to liquids (BTL), liquefied natural gas (LNG) and gas to liquids (GTL).

A staged evaluation methodology was developed to characterize, quantify, and mitigate carbon emissions from unconventional resources. Alternative processes for capturing carbon dioxide (CO_2) from the specific facilities are evaluated for economic and technical feasibility, and a technology based mitigation plan centered on carbon capture

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doi:10.1016/j.egypro.2009.02.210

and sequestration (CCS) is developed. The ultimate goal of this project is to enable the future, successful utilization of unconventional resources in a carbon constrained world.

This methodology was implemented to characterize the impact of mitigating carbon emissions in a GTL plant. Baseline carbon dioxide emissions levels from a generic GTL plant were established. The cost of mitigating these emissions using proven, post-combustion carbon capture technology were calculated. Oxy-firing GTL plant heaters was evaluated as an alternative, based on a Carbon Capture Project (CCP1) study [1] that indicated that this technology decreased the cost of CO_2 avoided by 38% compared to post-combustion capture in a refinery scenario. Technical and economic feasibility was compared for the two CO_2 capture technologies.

2. Methodology

In this staged methodology for evaluating and mitigating carbon emissions, CO_2 capture schemes are evaluated in order of increasing technological risk:

1. Develop the baseline case: quantify CO_2 emissions from a generic GTL plant without CO_2 capture
2. Design a retrofit CO_2 capture facility based on post-combustion CO_2 capture with no process/facilities integration with existing GTL plant
3. Design a new GTL facility with a minimal pre-investment that makes provisions for future integration with CO_2 capture facility. Consider traditional as well as emerging capture technologies. Oxy-firing technology was chosen for the GTL scenario.
4. Design a new GTL facility to be fully integrated with the CO_2 capture facility

Steps one, two, and three in this methodology have been completed for the GTL case and are summarized in this report. Designs and cost estimates for future CO_2 capture schemes fully integrated with the GTL process (Step 4) are ongoing.

3. Study Basis

3.1. GTL Plant Study Basis

The study is based on a generic GTL plant utilizing technology consisting of syngas generation, Fischer-Tropsch synthesis, and product upgrading. The GTL plant produces nominally 34,300 bbl/day liquid products and is assumed to have an on-stream factor of 90%. Unmitigated CO_2 emissions were quantified using a comprehensive Aspen Plus model of a GTL plant.

3.2. CO_2 Capture Plant Cost Estimate Basis

The study basis includes the cost of CO_2 capture, purification, and associated utilities. Product CO_2 specifications are based on generating a pure stream of CO_2 that is ready for pipeline transportation and storage: less than 3% inert content (Ar, O_2, N_2, etc), pressure of 103 bar, and temperature less than 70°C. The costs associated with CO_2 transportation, storage, and monitoring are highly site specific and are thus excluded from the scope of this study.

The capture plants are designed to be stand-alone. All utilities, including power, heating, and cooling are generated without any integration with the existing GTL plant. There is an exception in that 61.5 tonnes/hr of medium pressure steam (11 barg and 188°C) is simply condensed in the Base Case GTL process as there is no local use for it. This “free” steam is considered to be available for use in the capture plant.

For the purpose of calculating operating costs, the site is assumed to be a typical remote location where a GTL facility would be economically viable. The implications of a remote physical location include inexpensive fuel gas costs compared to developed locations and no available import or export of process utilities. Capital costs of the carbon capture facilities are based on instantaneous 1st quarter 2007 costs on the US Gulf Coast.

3.3. Post-Combustion Capture Plant Basis

The capital and operating costs for a post-combustion CO_2 capture plant were estimated. The capture plant uses a re-circulating monoethanolamine (MEA) to scrub CO_2 from the flue gases. Based on the simulated GTL flue gas data, process flow diagrams were developed, equipment was sized, and cost estimates were determined.

The capture plant design is based on 90% CO_2 recovery from the capture plant feed. Approximately 6% of the feed gas is vented to the atmosphere through the vent stack to avoid backpressure on the GTL process while preventing oxygen ingress into the capture plant. Capturing incremental additional CO_2 emissions from the capture plant utilities is not included in the capture plant design.

3.4. Oxy-fired CO_2 Capture Plant Basis

For the oxy-fired CO_2 capture technology, it was assumed that the furnaces would be designed for conversion to firing on pure oxygen upon the enactment of regulations constraining CO_2 emissions. The scope of the capture plant includes the heater design modifications, oxygen source, flue gas dehydration, flue gas purification, and required utilities. Aspen Plus® modeling software was used to model the oxy-fired GTL plant heaters and subsequent CO_2 separation, purification, and compression. The cost estimate for standard equipment was generated using Aspen Icarus Process Evaluator® software. Equipment quotes were sought for high-cost and lump-sum-turn-key (LSTK) items, such as the cryogenic air separation unit and gas turbo-generator. Consistent with the post-combustion case, the additional CO_2 generated in the capture plant utilities was emitted to the atmosphere rather than captured.

4. Process Description

4.1. GTL Process Description

The gas to liquids process is a means to monetize medium to large reserves of natural gas via chemical conversion to transportable liquids. See Figure 1 for a process schematic.

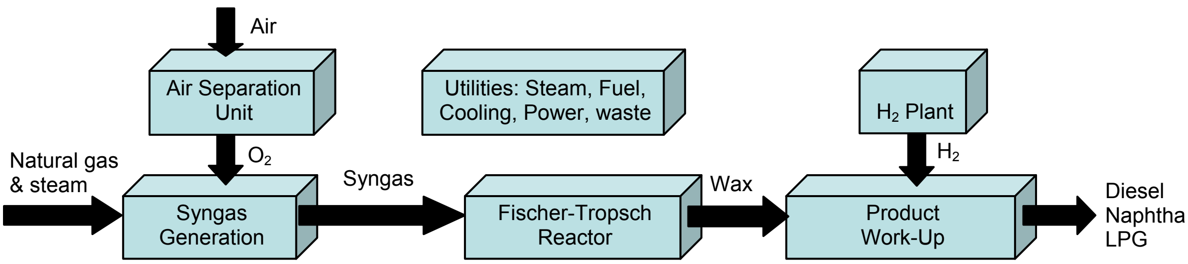

Figure 1: GTL Plant Block Flow Diagram

Natural gas is combined with steam and pure oxygen from a cryogenic air separation unit before it is heated and fed into an autothermal reformer (ATR). Syngas, a mixture of H_2 and CO, leaves the ATR and enters the Fischer-Tropsch (FT) synthesis reactor, where it is converted to a hydrocarbon wax. The wax exiting the FT reactor is upgraded in the product work-up unit to yield approximately 70% diesel and 30% naphtha liquid products. A steam-methane reforming hydrogen plant is required to provide hydrogen for the product upgrading as well as inlet natural gas pre-treatment. GTL plant CO_2 emissions comprise of five point sources, illustrated in the plot layout in Figure 2: H_2 plant, product workup unit, 2 ATR pre-heat trains, and the steam super-heater.

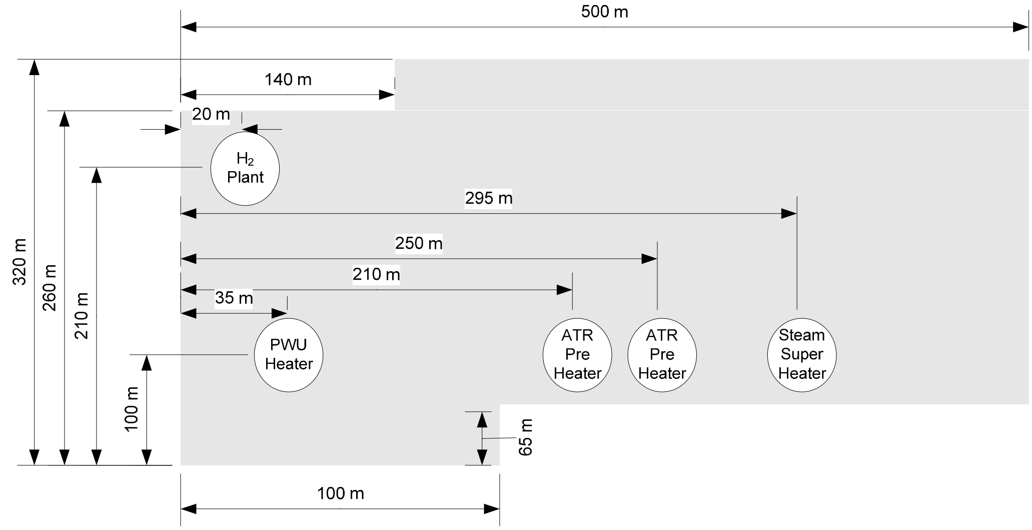

Figure 2: GTL Plot Layout (not to scale)

4.2. Post Combustion Capture Plant Process Description

A schematic of the basic post-combustion CO_2 capture process is illustrated in Figure 3. Various proprietary process designs have incorporated process and solvent enhancements over this generic process.

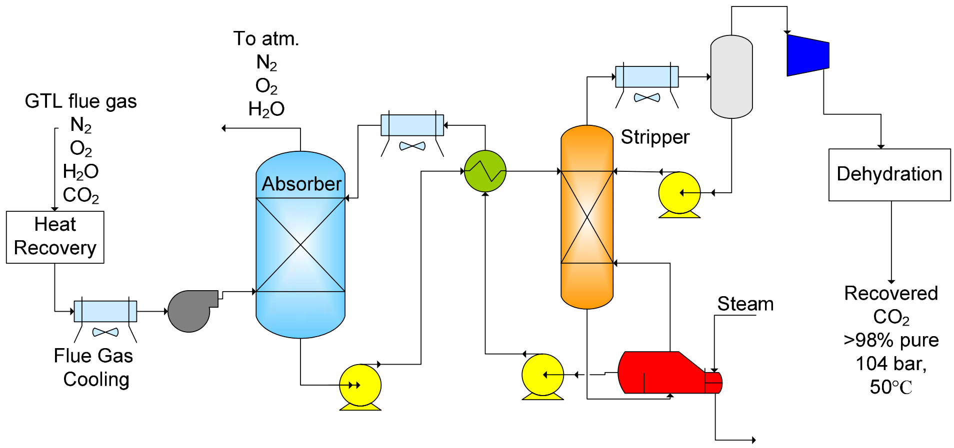

Figure 3: Generic Post-Combustion CO_2 Capture Plant Process Diagram

Flue gases exit the GTL process at temperatures ranging from 165 - 450°C. Heat recovery is included in the capture plant design to recover thermal energy. Due to the scattered locations of the CO_2 emissions sources in the GTL plant, two individual trains are necessary for heat recovery and flue gas cooling.

The cooled flue gases are combined and routed to a single train for CO_2 absorption, solvent regeneration, CO_2 dehydration, and CO_2 compression. The low pressure gas stream is contacted against a re-circulating amine solution. A reboiled amine stripper regenerates the amine and recovers an overhead stream of wet CO_2. The stripper overhead is cooled and sent to the CO_2 drying and compression train to meet the product specifications.

Key utility requirements from the post-combustion capture plant include power, steam, and cooling. Ancillary equipment supports the capture plant.

4.3. Oxy-fired CO_2 Capture Plant Process Description

In the oxy-fired CO_2 capture process, GTL heaters are designed to burn fuel in nearly pure oxygen rather than in air, generating a nitrogen-free flue gas. The heater duty, combustion temperature, flue gas temperature, and balance of radiant and convective duties are assumed to remain consistent between the air-fired base case and the oxy-fired case. As in the base GTL case, heater fuel is assumed to be provided by GTL process tail gas. In oxy-fired operation, the heater temperature is moderated by recycling a portion of the flue gas to dilute the oxygen feed and thereby keep the combustion temperature low enough for available materials of construction.

A large source of pure oxygen, one of the key requirements for using oxy-firing technology, is assumed to be generated in a cryogenic air separation unit (ASU). The ASU is designed to provide oxygen at 95% purity. Although cryogenic ASU's can provide higher purity oxygen, this is unnecessary since the GTL fuel gas already contains significant quantities of nitrogen that accumulate in the tail gas recycle stream.

The design of the CO_2 capture plant is based on local drying and compression of the five individual flue gas streams, followed by transportation to a central processing area for final inert removal and compression to the design specification. Some nitrogen is introduced to the flue gases with the oxygen and the fuel, necessitating downstream inert removal in which a refrigeration system separates the inert gases from CO_2 at low temperatures. Product CO_2 is compressed to the design pressure. Key utility requirements from the oxy-fired capture plant include power for the large ASU compressors and CO_2 compressors, and process cooling. A process schematic is illustrated in Figure 4 for one of the emissions points.

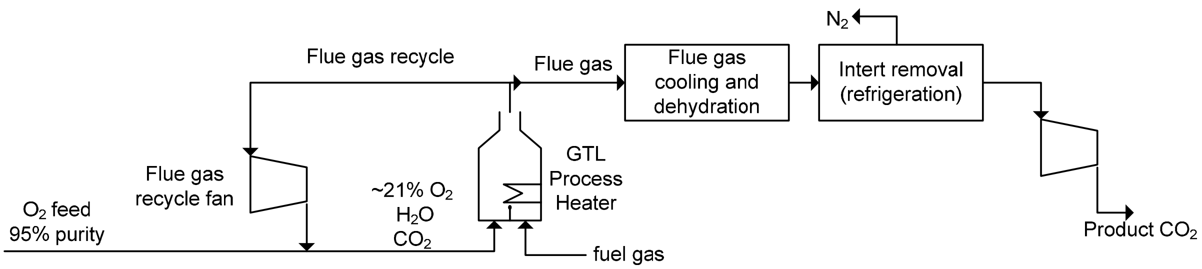

Figure 4: schematic of oxy-firing heaters plus CO_2 capture

5. Results

5.1. GTL Plant Emissions without CO_2 Capture

A GTL plant producing nominally 34,300 bbl/day liquid products was predicted to emit 1.6 MM tonnes/year CO_2 (90% on-stream).

The GTL plant CO_2 is generated from several sources:

- Entering with the inlet natural gas (feed gas assumed to contain 1.6 mol% CO_2)
- Forming during syngas generation
- Forming in the FT reactor
- Forming in the hydrogen plant
- Forming in the process heating furnaces

Process tail gases from the GTL plant are diverted to the plant fuel system. Therefore, the CO_2 that is generated in various locations in the plant is emitted via five different heater stacks:

- Two ATR pre-heater furnace train stacks
- Steam super-heater stack
- Hydrogen plant stack
- Product workup unit (PWU) stack

The detailed breakdown of the source and emission points of CO_2 in a GTL plant is illustrated in Figure 5.

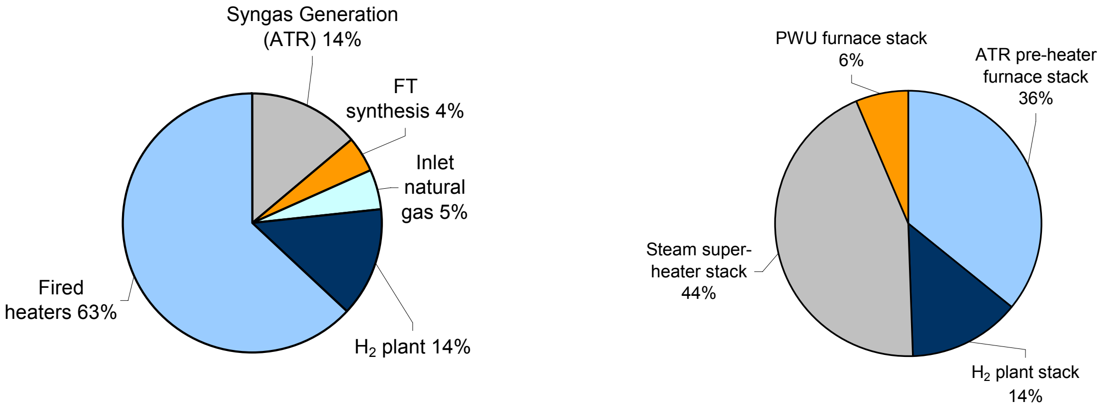

Figure 5: Left: Sources of CO_2 in a GTL plant; Right: Point emissions of CO_2 from a GTL plant

5.2. GTL Emissions With CO_2 Capture

A summary of the total CO_2 generated from the GTL plant and recovered using the two different capture technologies is shown in Table 1.

Table 1: CO_2 Emissions

Source of CO_2	Post Combustion CO_2 Emissions (MM tonnes/yr)	Oxy-firing CO_2 Emissions (MM tonnes/yr)
CO_2 generated in Base Case GTL plant (without CO_2 capture)	1.58	1.58
CO_2 generated in oxy-fired GTL plant (without CO_2 capture)	-	1.42
CO_2 generated in GTL + capture plant	1.71	1.66
CO_2 feed to capture plant	1.22*	1.42
CO_2 captured	1.04	1.34
CO_2 emitted (with capture)	0.67	0.32
CO_2 avoided	0.91	1.26

*In this study, only 70% of the GTL plant emissions were fed to the capture plant

In the post-combustion capture case, 61% of the net CO_2 is captured from the combined GTL and capture plant. A fraction of the flue gases were not fed to the capture plant in this study, accounting for approximately 30% of the CO_2 that was not captured. The balance of the CO_2 that is released to the atmosphere includes the CO_2 slip in the capture plant design and the CO_2 generated in the capture plant utilities.

In the case of oxy-fired GTL plant heaters, the switch from air firing to oxygen firing increased heater efficiency. From Table 1 it can be seen that this transition caused a 10% decrease in CO_2 emissions in the oxy-fired heaters. When capture plant utilities are considered, the net CO_2 captured in this case is 81%.

5.3. Post-Combustion Capital Costs

The capital cost of the retrofit, post-combustion, EFG+ capture plant is **$223,000,000** (-15%/+35%; instantaneous $US 1Q2007; US Gulf Coast; 15% contingency, includes technology licensing fee).

5.4. Oxy-fired heaters plus CO_2 Capture Capital Costs

The capital cost of converting the GTL plant to oxy-fired heaters is **$341,000,000** (-35%/+50%; instantaneous $US 1Q2007; US Gulf Coast; 20% contingency).

5.5. Operating Costs

The base case assumes that the GTL process is used for monetizing remote natural gas. Fuel costs tend to be exceptionally low in remote locations where there is no existing market for natural gas. Additionally, there is no available outlet for excess steam or power from the GTL plant, meaning that excess steam produced in the GTL plant is available for the capture plant. To better understand the effect of the remote GTL plant location and the availability of excess steam, a sensitivity case is included. In this sensitivity case, natural gas prices are assumed to be typical for North America, and it is assumed that the excess GTL plant steam is not available for use in the capture plant.

The operating cost comparison of the post-combustion and oxy-fired capture plants has been included in Table 2.

Table 2: Operating Costs ($US 2007)

	Post-Combustion Capture		Oxy-fired Capture	
	Base Case	Sensitivity Case	Base Case	Sensitivity Case
Base case natural gas fuel cost	$1.00/MMBTU	$7.5/MMBTU	$1.00/MMBTU	$7.5/MMBTU
Steam available from GTL plant	62 tonnes/hr	None	62 tonnes/hr	none
Annual Operating Cost	$6,526,000	$31,800,000	$8,700,000	$26,000,000

5.6. Cost of CO_2 Avoided

The Base case and the Sensitivity case were compared on the basis of the cost of CO_2 avoided in Table 3.

Table 3: CO_2 avoided cost: CO_2 Emissions expressed in MM tonne/year

	Post-Combustion Capture		Oxy-firing Capture	
	Base Case	Sensitivity Case	Base Case	Sensitivity Case
Gas Cost	\$1.00/MMBTU	\$7.5/MMBTU	\$1.00/MMBTU	\$7.5/MMBTU
GTL plant Steam Used	62 tonnes/hr	none	62 tonnes/hr	none
CO_2 captured	1.04	1.04	1.34	1.34
CO_2 avoided	0.91	0.83	1.26	1.24
CO_2 avoided cost*	**\$36/tonne CO_2**	**\$70/tonne CO_2**	**\$39/tonne CO_2**	**\$54/tonne CO_2**

*10% discount rate, 20 year project life

6. Conclusion

This study evaluated the impact of mitigating carbon emissions from a GTL facility by capturing CO_2 for geologic sequestration using two distinct technologies: post-combustion CO_2 capture and oxy-fired CO_2 capture. The evaluation focused on the cost of CO_2 capture, excluding the site-specific costs of CO_2 transportation and storage.

A generic GTL plant was calculated to release 1.6 MM tonnes/year CO_2 emissions for a 34,300 bbl/day facility. A techno-economic evaluation of a retrofit, post-combustion capture plant determined the cost of capturing GTL emissions without integrating with the GTL process. Oxy-firing GTL plant heaters was evaluated as an alternative capture technology and compared to the baseline post-combustion case. The results of the baseline and alternative CO_2 capture technologies applied to the GTL plant are included in Table 4.

Table 4: Capture Technology Comparison for a Gas-to-Liquids Plant

	BASELINE: post-combustion	ALTERNATE: oxy-firing	% change
CO_2 avoided (MM tonnes/year)	0.9	1.3	
% total CO_2 captured (GTL plus capture plant)	61%	81%	
Capital Cost (\$US 2007 -35%/+50%)	\$223,000,000	\$341,000,000	
Base Case CO_2 avoided cost (remote site assumptions)	\$36/tonne CO_2	\$39/tonne CO_2	8%
Sensitivity Case CO_2 avoided cost (non-remote site)	\$70/tonne CO_2	\$54/tonne CO_2	-23%

Oxy-fired CO_2 capture technology has an 8% higher cost of CO_2 avoided compared to post-combustion capture for the GTL scenario. This unexpected result is due to site specific economic issues deriving from the remote site assumption. The economic environment in the remote GTL plant scenario is dominated by high capital costs and low operating costs, and in this cost atmosphere, post-combustion technology is favored over oxy-firing. The sensitivity study demonstrates this location effect; in an environment of high energy costs, oxy-firing is shown to decrease the cost of CO_2 avoided by 23% compared to post-combustion technology. This study shows that it is important to consider site-specific issues when comparing the cost of CO_2 capture for different applications. There is an opportunity to decrease the cost of CO_2 capture from remote, unconventional resources such as GTL by taking advantage of the low cost of energy in some remote locations.

7. References

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